SOME ASPECTS OF WATERSHED MANAGEMENT IN SOUTHERN CALIFORNIA

By

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STEPHEN N. WYCKOFF, DIRECTOR

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FOREWORD

The material presented in this publication was prepared in May 1947, for a watershed-management seminar held at that time on the San Dimas Experimental Forest. The seminar was attended by members of the Forest Influences Division of the California Forest and Range Experiment Station, representatives of the Forest Service Regional Office in San Francisco, and staffs of the Los Padres, Angeles, San Bernardino, and Cleveland National Forests in southern California.

The discussions prepared by the Experiment Station staff were summarized and mimeographed, and copies were distributed among the group attending the seminar. The supply of copies remaining for distribution after the seminar was soon exhausted, but requests for copies are still being received. The present edition is intended to satisfy these requests and to provide wider dissemination of the seminar discussions.

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INTRODUCTION

C. J. Kraebel and J. D. Sinclair

Most of California's water supply originates in its mountain areas, about half of which are occupied by the 18 national forests of the State. While the mountains receive from 30 to 90 inches of rainfall annually, the valleys in general receive less than 15 inches. The runoff of mountain water is depended upon for hydroelectric power, for irrigation, and for domestic and industrial use. In this rapidly growing State, the water yield of the mountain forests is fully as important a resource as are lumber and forage.

The first Forest Reserves were established in southern California more than 50 years ago, primarily to protect mountain watersheds and insure the continuation of local water supplies. These one-time reserves are now known as the Angeles, Cleveland, Los Padres, and San Bernardino National Forests, embracing about 3,400,000 acres of southwestern California from Monterey County to the Mexican border.

Watershed protection has assumed increasing importance through the decades. Today the problems of water shortage, floods, and erosion in southern California are among the most serious in the United States. They result from a unique combination of natural conditions, a dense population, and vast developments in agriculture and industry. Some 5,000,000 acres of rugged mountains, upon which the principal cover is brush, with limited stands of timber, are the source areas of local water supplies essential to the population living in valleys. Southern California supports about 50 percent of the State's population and is still growing rapidly; yet this region has somewhat less than 2 percent of the State's water supply. It is generally recognized that shortage of water will be the limiting factor in the future development of this area. Conversely, these mountain watersheds are sources of disastrous floods, causing loss of life and destruction of property.

Studying the influence of vegetation on water yield, soil stability, and local climate is the job of the Division of Forest Influences of the California Forest and Range Experiment Station. Its long-range objective is to develop principles and methods for managing mountain watershed lands to produce the maximum yield of usable water compatible with adequate control of soil erosion and floods, and with other legitimate uses of those lands.

Specifically, forest influences research seeks, (1) to determine the effects upon water yield of forest uses and abuses (including lumbering, grazing, road building, and fire), (2) to devise methods for correcting poor forest practices or repairing watershed injuries that damage the water crop, (3) to develop principles and methods of forest management which will improve the quality and quantity of water yield.

The research program is directed from Berkeley headquarters, using experimental forests, smaller work centers in special problem areas, field surveys, and special "hot-spot" studies as required. Work centers have been established in the San Joaquin and Kings River watersheds, tributary to California's great Central Valley, and local studies have been made as needed elsewhere in the State. But the principal research effort has been centered south of the Tehachapi Mountains because water shortage, flood, and erosion problems are most acute in southern California.

Preliminary studies of the relation of watershed condition to streamflow and erosion were begun in southern California by the Forest Service more than thirty years ago. After an interruption of several years, these studies were resumed in 1927 by the California Forest and Range Experiment Station at Devil Canyon on the San Bernardino National Forest. In 1933 the Station began a comprehensive program of watershed research on a portion of the Angeles National Forest specially designated as the San Dimas Experimental Forest.

The objectives of research at this experimental forest are: (1) to study the influence of watershed conditions, including topography, geology, soils, and vegetation, on disposition of rainfall and (2) to develop methods of watershed management which will assure both the maximum yield of usable water, and satisfactory regulation of flood runoff and erosion. Intensive studies are being made of precipitation, streamflow, erosion, and the use of water by vegetation. Results of the work will have specific application in the mountains of southern California, but some of the principles developed there will have application to similar problems elsewhere in the world.

During 1945 and 1946 the Division of Forest Influences and Fire Control have cooperated in a special study of watershed conditions in the national forests from San Luis Obispo to the Mexican border -- to determine, among other things, the effects of watershed denudation by fire on the size of floods and rates of erosion in some 240 mountain watersheds. This study has brought together and analyzed much information which should help to improve our understanding and practice of watershed management in southern California. In the present paper only a few sample results of that study are included. The full reports will be supplied to the forests as they are completed.

THE CLIMATE OF SOUTHERN CALIFORNIA

E. L. Hamilton

Located in the path of prevailing westerly winds of the Pacific Ocean, the coastal portion of southern California enjoys a Mediterranean type of climate. Coastal fogs frequently extend to the summit of the coast mountain ranges. The interior mountains act as a barrier to the cold air from the north, and air from the interior plateau is warmed as it descends the slopes to the valley plains. Mean monthly temperatures range from about 45° to 76° F. Minimum temperatures rarely drop below 10° F. and maxima of 115° F. are not uncommon at the lower elevations. Maximum temperatures of 100° F. have been recorded at stations 5,000 feet above sea level.

The amount of precipitation received by any locality in this region depends upon its distance from the ocean, the altitude, the shape and steepness of mountain slopes, and the direction of the slopes in relation to the direction of moisture-bearing winds. As a rule, precipitation increases from south to north and is much heavier on southern and western than on northern or eastern mountain slopes.

In southern California almost all of the precipitation occurs between October and April, as is shown for the San Dimas Experimental Forest in Table 1. The four wettest months, December, January, February, and March, produce 78 percent of the annual total. This rain normally occurs in about twenty storms per season. The summer rainfall, such as it is, is derived principally from sporadic thunderstorms which originate over the great deserts and reach their maximum development over the mountains. These Sonora-type showers appear to be especially prevalent in the high country of the San Bernardino National Forest. Snow is practically unknown at the lower elevations but falls in appreciable amounts at elevations above 4,000 feet. Annual snowfalls reach 200 inches at elevated stations, with an approximate average of 60 inches yearly at 6,000 feet.

The concentration of exceedingly heavy rainfall in a few months creates special problems for the watershed manager in southern California. Illustrative of the high intensities of rainfall in this region are the following records: In 1926, at Opid's Camp in the Angeles National Forest, 1.02 inches of rain fell in 1 minute, a world record. In 1891 at Campo, in San Diego County, 11.50 inches of rain fell in one hour and 20 minutes (a world record until exceeded at Holt, Missouri, in June 1947). On January 22, 1943, 26.12 inches of rain fell in a 24-hour period at Camp LeRoy, Angeles National Forest, establishing a new record for the United States.

Most of the precipitation occurs in a few of the winter storms. During a 14-year period on the San Dimas Experimental Forest, 23 percent of the total precipitation fell in 3 percent of the storms; yet 30 percent of the storms produced only about 2 percent of the rainfall. Details of rainfall distribution are shown in Table 2.

The average annual rainfall at several different locations on each of the four southern California national forests is shown in Table 3. The last two columns in the table show the wide range in annual rainfall experienced over the period of time since the recording was started.

Table 1.- Number of storms and total rainfall by months for the period 1933 to 1947, San Dimas Experimental Forest 1/

Month	Storms		Rainfall	
	Number	Percent	Inches	Percent
October	25	9.3	23.66	5.2
November	18	6.7	31.69	7.0
December	43	16.0	99.09	21.9
January	33	12.3	62.68	13.9
February	42	15.6	106.60	23.6
March	47	17.5	84.74	18.7
April	34	12.7	30.91	6.8
May	10	3.7	2.74	.6
June	6	2.2	1.61	.4
July	0	-	.11	.02
August	4	1.5	1.56	.3
September	6	2.2	6.80	1.5
Total	268	100	452.19	100

1/ Standard raingage at Tanbark Flat (elevation 2750 feet) on the San Dimas Experimental Forest.

Table 2.- Number of storms and amounts of rainfall by storm size classes for the period 1933-1947, San Dimas Experimental Forest 1/

Storm size class, inches	Storms		Rainfall	
	Number	Percent	Inches	Percent
0 - .25	95	30	11.30	2
.26 - .50	47	15	16.98	3
.51 - 1.00	62	20	45.86	10
1.01 - 2.00	47	15	68.49	15
2.01 - 3.00	22	7	53.51	12
3.01 - 4.00	9	3	31.24	7
4.01 - 5.00	9	3	39.50	9
5.01 - 6.00	8	2	43.23	10
6.01 - 7.00	6	2	39.07	9
over 7.00	9	3	103.01	23
Total	314	100	452.19	100

1/ Standard raingage at Tanbark Flat (elevation 2750 feet).

Table 3.- Precipitation recorded at selected locations in four southern California forests 1/

Location and national forest	Elevation above sea level	Annual rainfall: Average	Annual rainfall: Minimum	Annual rainfall: Maximum
	Feet	Inches	Inches	Inches
LOS PADRES N.F.				
Jolon	960	17.29	5	34
Santa Barbara	130	18.04	6	43
Cuyamaca	--	10.13	5	18
Mono Ranch	3210	34.21	14	55
ANGELES N.F.				
Los Angeles	338	14.95	4	40
Newhall	1200	17.55	4	39
Tanbark Flat	3750	28.25	7	70
Mount Wilson	5850	31.20	8	80
SAN BERNARDINO N.F.				
Santa Ana River	2850	28.08	11	47
Cajon	2700	13.53	6	24
Bear Valley	6700	35.85	13	95
CLEVELAND N.F.				
San Diego	87	9.67	3	17
Barrett	1600	19.36	8	33
Campo	3000	19.92	9	34
Julian	4222	33.26	20	57

1/ Lengths of record variable; all records terminate in 1947.

GEOLOGY AND SOILS

H. C. Storey

GEOLOGY

Geology is important in any consideration of factors influencing watershed behavior. This is particularly true in the Los Padres, Angeles, San Bernardino, and Cleveland National Forests, in which the soil mantle is relatively thin. Although geology is not one of the hydrologic factors that can be altered by man, it is important to know what the capacity of the rock may be for the entrance and storage of water. Any program of watershed management leading to increased infiltration of water must presuppose adequate storage in the soil and rock to handle this additional volume. Moreover, the degree and rate of weathering for the different rocks has an important bearing on erosion.

For hydrologic purposes, the rocks of southern California may be grouped in two main divisions: (1) sedimentary; (2) igneous and metamorphic. There is considerable variation in the water-carrying capacity and the susceptibility to erosion of these formations.

Sedimentary formations, consisting of interbedded shales, sandstones and conglomerates, underlie almost the entire forest area north of the Santa Clara River. Laid down in the Cenezoic Era (during the past 60 million years), they vary in water-holding capacity and erosibility according to their composition and the position of their bedding planes. Coarse-grained, loosely compacted sandstone or conglomerate allows ready entry and movement of water. Such rocks usually form good sources of water for wells. On the other hand, a hard, platey shale furnishes great resistance to water movement, particularly movement at right angles to the bedding plane. Generally speaking, in formations of interbedded sandstones and shales, the shales are eroding faster than the sandstone. Normally, none of these sedimentary formations break up as badly when faulted as do the igneous and metamorphic crystalline rocks.

The igneous formations consist largely of granitic types, varying from true granites to diorites. These rocks underlie large areas of the Angeles, San Bernardino, and Cleveland National Forests. There are some volcanics, but these are generally very localized. The largest part of the granitic rocks occur in the form of massive batholithic bodies made up of several successive intrusions. (The most active period of intrusion was some 130 million years ago in the Jurassic Period.) This type of rock does not carry water between its constituent minerals, but rather along the joint planes and fractures caused by faulting. The great amount of jointing and fracturing has allowed ready access to weathering agents, and for this reason weathering is often deep and the surface material easily eroded.

The metamorphic rocks, consisting of schists and gneisses, were formed by alteration of both sedimentary and igneous rocks. These formations may strongly resemble sedimentary rocks because of a pseudobedding developed by the alignment of minerals during the process of metamorphism. These rocks vary greatly in their capacity to receive and store water. Practically no water is carried within the rock structure, but because of the great age of these rocks and the consequent long period of repeated faulting and fracturing, there are abundant cracks for water passage. These rocks, as well as the igneous types, are largely crystalline and tend to shatter extensively when faulting occurs. The large amount of fracturing plus the tendency to break along schist planes causes these rocks to weather fairly rapidly.

Faulting is very extensive in southern California and has important hydrologic implications. The shattered rock allows ready penetration and storage of water. Large crush zones favor rapid erosion. The major fault zone of this area, and the entire State, is the San Andreas Fault. This fault traverses about three-fourths of the length of the State, starting north of Pt. Arena (Mendocino County), running southeast along Tomales Bay, through western San Francisco, along the east side of the Santa Cruz Mountains, along the upper Pajaro River, and along the Temblor Range and Elkhorn Hills east of the Cuyama Valley. There it swings more to the east and passes north of Mt. Pinos and Frazier Mountain, past Lebec, along the north side of the San Gabriel Mountains, through Cajon Pass, along the south side of the San Bernardino Mountains, through San Gorgonio Pass and thence on into the Salton Sea Basin. Horizontal displacement along this fault has been estimated to be as much as 40 miles. A horizontal movement of 20 to 30 feet along this fault zone caused the famous San Francisco earthquake. Major branches of this fault are quite active, having had periods of recent movement. The presence of a series of hot springs in this area usually indicates the location of a recently active fault.

Underground basins, the largest of which are located along the south side of the San Gabriel Mountains, are important to the water supply of southern California because of the large quantities of water that they can hold. These basins are filled with thick deposits of sand, gravel, and boulders that have been carried down from the mountains and deposited in the valleys. The basins are bounded by impervious rock ledges and fault planes. The relatively large amount of pore space in the fill material, coupled with the impervious boundary formations, makes these basins ideal underground storage reservoirs that are protected against excessive water losses through evaporation. Water reaches the basins by infiltration of rainfall, by percolation from streams, and by deep percolation through rocks of the adjacent mountain masses.

SOILS

The soils found in the four southern forests vary considerably, both in composition and depth. Compared with valley soils the mountain soils are generally not very deep; limited areas are 6 to 8 feet deep; large areas are 3 feet or less in depth, and in some places soil depth is measured in inches.

Owing to their youthful nature, the soils correlate quite closely with the geology, in most cases consisting of physically disintegrated parent rock. Some scattered locations show the beginning of profile development, for example, the flat upland country in the Cleveland National Forest and the old alluvial fans along the south front of the San Gabriel and San Bernardino Mountains. Here may be found a higher percentage of clay, due to the chemical decomposition of the feldspar particles.

Whether deep or shallow, the watershed soils serve as an important water-regulating medium. At the beginning of the rainy season, soil moisture is at or below the wilting point, and the capacity of the soil to store water is at or near its maximum. At that point soils 2 feet deep may absorb from 2 to 4 inches of rain before they reach field capacity.[1]

As soon as the soil moisture reaches field capacity, drainage into the underlying rock structure begins. At that point, some storage space for water still remains in the soil, namely the volume between field capacity and saturation. Where the capacity of the underlying rock to take in water is less than that of the soil, the storage space in the soil serves as a temporary reservoir, reducing surface runoff and allowing additional time for the water to enter the rock. A good vegetative cover insures the maintenance of a high soil infiltration capacity, thus protecting the regulating quality of the soil. Therefore, to maintain such a vegetative cover is a primary objective of watershed management.

Soils vary considerably in their erosibility, both as to rate and type. The deep clayey soils of the meadows in the Cleveland National Forest erode very rapidly if the vegetative cover is disturbed, and extensive gully systems result. The sandy, gravelly soils on the slopes are more subject to sheet erosion. Barren areas of sandy or gravelly soil sometimes tend to develop a comparatively low rate of erosion because of the formation of an erosion pavement. This occurs largely in areas where there are abundant rock fragments mixed through the soil; when the fines are removed, the rock residue completely covers the surface, slowing the velocity of surface runoff, covering the soil beneath, and materially reducing the erosion rate.

1/ Field capacity represents the maximum amount of water that can be held in the soil against gravity drainage. It is usually considered to be the moisture content of a soil after two or three days drainage following a large storm or heavy irrigation.

VEGETATION

J. S. Horton

The mountain land of southern California is covered mainly by chaparral, woodland, and forest. These three major plant formations are broken into several component cover types. An understanding of the natural plant cover and the ways in which it is affected by forest fire is of the greatest importance to watershed managers.

The chaparral formation, a dense growth of many shrub species, presents the most critical problems of watershed management because it extends over a large area in which the precipitation may occur as intense rain storms; because the chaparral is highly inflammable; and because destruction of the plant cover suddenly increases the opportunity for flood and erosion damage and decreases the yield of usable water.

Chaparral grows at elevations of 1,000 to 5,000 feet above sea level, usually on loose soils and steep slopes that favor rapid runoff and high erosion rates when denuded of the protecting plant cover. Increases in runoff and erosion are felt for many years while the chaparral recovers. Moreover, burning tends to perpetuate and extend the chaparral into areas originally occupied by the other plant formations, thereby increasing the extent of the problem area.

The woodland formation is an open stand of trees, usually having a ground cover of grass and small shrubs. Woodland grows generally at elevations below 5,000 feet. The typical woodland formation on the coastal side of the mountains is an oak-grass-sage complex that is best developed on the Cleveland and Los Padres National Forests. On the desert side of the mountains, the woodland formation is dominated by pinyon pine and juniper. Both types of woodland suffer from forest fire, and throughout much of their range have probably been replaced by chaparral because they have been burned more frequently in historical times than in earlier periods. Woodland is a valuable watershed protection cover, and its management problems are somewhat less critical than those of the chaparral.

The forest formation is developed at elevations generally above 5,000 feet, where the winter precipitation occurs largely as snow. Maintenance of the forest cover is important in good watershed management, but the problems of its protection are also less critical than those of the chaparral. However, since the coniferous trees do not sprout, burning of the forest often results in the replacement of forest areas by chaparral or woodland. Charred stumps show that the extent of the true forest in southern California has been appreciably reduced by cutting and fire during the period of occupancy by the white man.

All the major plant formations are profoundly affected by fire, which causes changes in their component species, reduces the range of some cover types, and extends the range of others. Fires in the past may have played as important a part as altitude and climate in determining the main characteristics and distribution of the major plant formations. Therefore, any analysis of the native vegetation of southern California in relation to watershed management is bound to consider fire and its effects at every turn. For example, from the long range viewpoint, the chaparral may be called a "fire type" of vegetation because it retains its identity as a plant formation and holds its ground despite repeated burning. Further, many of its component species actually require fire for their reproduction and survival. Before there was any human occupancy of southern California lightning was practically the only cause of fire. It is highly probable that the frequency of burning has increased since man first appeared in the area. If lightning fires had not occurred in the prehuman period most of what is now the chaparral formation would probably have been occupied by coniferous forests at the higher altitudes, and by the oak-woodland-grassland-sagebrush complex lower down.

For convenience in study and management, the vegetation of southern California may be broadly classified as follows:

- Chaparral formation
  - Chamise chaparral type
  - Sage-buckwheat type
  - Scrub oak type
  - Desert chaparral
- Woodland formation
  - Coastal oak type
  - Pinyon-juniper type
- Forest formation
  - Jeffrey (or ponderosa) pine type
  - Ponderosa (or Jeffrey) pine-white fir type
  - Sugar pine-white fir type
  - Lodgepole (or limber) pine type
  - Bigcone-spruce (or Coulter pine) type

CHAPARRAL FORMATION

Chaparral occupies the bulk of the watershed area in the four national forests of southern California. This formation probably developed during the geologic period (before the arrival of man) when the mountains were uplifted. During this period lightning fires were probably frequent enough to insure perpetuation of the chaparral formation and to prevent its replacement by woodland or forest, which would otherwise have been the natural course of plant succession.

Chamise-chaparral type

Chamise (*Adenostoma fasciculatum*) is the most widely distributed species of the chaparral formation. It occurs in pure and mixed stands on all sites except north-facing slopes and extremely dry south-facing slopes. This species may be associated with hoaryleaf ceanothus (*Ceanothus crassifolius*), buckbrush (*Ceanothus cuneatus*), white sage (*Salvia apiana*), black sage (*Salvia mellifera*), bigberry manzanita (*Arctostaphylos glauca*), Eastwood manzanita (*Arctostaphylos glandulosa*), or other minor chaparral species.

Besides extending the range of chaparral, fires since the coming of man have probably changed the relative percentages of the associated species in the chamise chaparral type. Hoaryleaf ceanothus and buckbrush thrive under repeated burning. Because they are short-lived species, they may be expected to disappear in the relatively short span of 100 years if the chaparral is not reburned. On the other hand, if the chaparral is reburned oftener than once every 20 years, the long-lived bigberry manzanita will probably disappear because the plants of this species are slow growing and do not produce abundant seed crops until the shrubs are about 20 years old.

There is too little evidence to show conclusively what would replace the chamise chaparral type if fire were eliminated as a habitat factor. There are some indications that California live oak (*Quercus agrifolia*) and some of the chaparral species such as hollyleaf cherry (*Prunus ilicifolia*), laurel sumac (*Rhus laurina*), or hollyleaf redberry (*Rhamnus crocea* var. *ilicifolia*) would slowly invade and take the place of the chamise. As the sites on which chamise grows are not good enough to support a heavy cover of these species, it is probable that the stand would be open, with inter-shrub spaces covered by grass or sage, depending upon the soil characteristics. It must be pointed out that the rate of this invasion is extremely slow.

Sage buckwheat type

Dry sites in the chaparral formation, which usually have unstable soil, are dominated by white sage, California buckwheat (*Erigonum fasciculatum* var. *foliolosum*), and other shrubs of similar character. Also, certain geologic formations such as unconsolidated sediments favor development of the sage-buckwheat type.

According to field evidence, burning does not control the distribution of sage and buckwheat. The boundary between sage and chamise chaparral appears to remain practically constant, regardless of the frequency of fire.

Scrub oak type

Chaparral consisting of California scrub oak (*Quercus dumosa*) associated with hairy ceanothus (*Ceanothus oliganthus*), or other chaparral species within their range, is found on north-facing slopes. Above 4,000 feet, the California scrub oak is usually replaced by interior live oak (*Quercus wislizenii*), but the type sometimes occurs on south-facing slopes at these altitudes. The scrub oak type is not destroyed by fire.

Desert chaparral

An open chaparral is developed where rain is deficient, as on the desert side of the mountains or in local areas such as Piru Creek canyon or the upper Cuyama River valley. The openness of the stand is not condusive to severe burning, and hence chamise and the other chaparral species that require fire for survival are absent. Oak, manzanita, sugar bush (*Rhus ovata*), flannel bush (*Fremontia californica*), and the several varieties of desert ceanothus (*Ceanothus greggii*) are the most abundant plants. This association occupies the same altitudinal limits as the pinyon woodland and frequently replaces pinyon pines destroyed by fire.

WOODLAND FORMATION

Coastal oak type

An oak woodland consisting primarily of California live oak, often associated with other tree species, develops in canyon bottoms and other areas (especially near the coast) that are somewhat protected from the severe fires that ravage the chaparral slopes.

This oak woodland is a complex grouping of oak, sage, and grass species. California live oak is the principal dominant, but it may be associated with Engelmann oak (*Quercus engelmannii*) in the Cleveland National Forest, and California white oak (*Quercus lobata*) and blue oak (*Quercus douglasii*) in Los Padres National Forest. The sage components are usually species of subshrubs -- sage (*Salvia*), sagebrush (*Artemisia*), or buckwheat (*Eriogonum*) -- with a great variety of associated subshrubs, perennial and annual herbs, and grasses.

After severe burning, established California live oaks may sprout and ultimately restore their dominance. The Engelmann, California white, and blue oaks are more apt to be killed. Seeds of the chaparral species usually germinate more vigorously after fire than seeds of the woodland species. Hence fire tends to spread the chaparral type into the oak woodland. A large portion of the oak woodland (especially in the northern Los Padres) has been converted to a chaparral type by the increased burning during human occupancy of the region.

The spread of oak woodland into areas dominated by cover types which are favored by fire is extremely slow. For example, invasion of the California live oak into scrub-oak chaparral starts rather soon after the chaparral reaches maturity, but growth of the live oak seedlings is so slow that unless the area is protected for many years -- probably centuries -- the young oaks may not withstand the effects of a severe fire.

Pinyon-juniper type

Pinyon pine or juniper woodland occurs on the desert side of the main mountain ranges. The pinyon pine (*Pinus monophylla*), and to a lesser extent the California juniper (*Juniperus californica*), is usually associated with the desert chaparral species discussed previously. In the Big Bear Lake region, Sierra juniper (*Juniperus occidentalis*) or pinyon pine are associated with subshrub species.

If fires burn through this woodland, the trees are largely removed and the area is converted to an open chaparral or sagebrush. Fires are relatively infrequent in the pinyon-juniper type, however, because of the scanty plant growth.

FOREST FORMATION

The forest formation is composed of coniferous trees of 9 principal species, including 6 pines. The forest zones usually receive 30 inches or more annual rainfall. Where the rainfall is less than 30 inches, the forests do not extend much below 6,000 feet elevation.

Increased frequency of fire since the coming of man has somewhat reduced the area covered by coniferous forest. Some brushfields are now found within the forest area, and there are indications that, throughout a significant percentage of its range at lower altitudes, the forest has been replaced by chaparral or woodland. Fires in the prehuman period, however, perpetuated a certain percentage of the fire-caused chaparral and woodland and undoubtedly prevented the forest from developing on some sites suitable for the growth of coniferous trees.

Jeffrey (or ponderosa) pine type

Open forests of Jeffrey pine (*Pinus jeffreyi*) or ponderosa pine (*Pinus ponderosa*) are found on the poorer soils or in areas of limited rainfall within the forest zones. Burning will kill most young coniferous trees but will usually only scorch the trunks of mature trees. It may, however, cause a considerable increase of associated chaparral species such as deerbrush (*Ceanothus integerrimus*), mountain whitethorn (*Ceanothus cordulatus*), pine manzanita (*Arctostaphylos parryana* var. *pinetorum*) and bush chinquapin (*Castanopsis sempevirens*). If the mature trees are logged, fires after logging may change this forest to a chaparral type or to a woodland of California black oak (*Quercus kelloggii*).

Ponderosa (or Jeffrey) pine-white fir type

On the better sites where moisture is adequate there is developed a dense forest of ponderosa or Jeffrey pine, sugar pine (*Pinus lambertiana*), white fir (*Abies concolor*) and incense cedar (*Libocedrus decurrens*). In some instances after logging and fire, this forest will be replaced by black oak woodland or by chaparral.

Sugar pine-white fir type

This is an open forest that grows on steep unstable slopes. Jeffrey pine is almost always associated with the sugar pine and white fir. Occasionally sugar pines occur only as scattered individuals. Fires rarely burn in this type because of the widely spaced trees and the general lack of shrub or herbaceous cover. When fires do occur they tend to increase the relative abundance of chaparral shrubs.

Lodgepole (or limber) pine type

These alpine species of pines (Pinus contorta var. latifolia and P. flexilis) grow in open stands at high elevations, usually above 8,000 feet. The ground cover is naturally sparse, and there is much bare soil and rock; hence fire hazard is low, and the infrequent burning has no appreciable effect on the composition of the stand.

Bigcone-spruce (or Coulter pine) type

Bigcone-spruce (Pseudotsuga macrocarpa) and occasionally Coulter pine (Pinus coulteri) are found at altitudes between 4,000 and 6,000 feet, or even higher if rainfall is deficient. The bigcone-spruce forest and its associated chaparral and woodland types constitute a "tension zone" between the chaparral of lower elevations and the forest above. North-facing slopes in this zone are occupied by stands of bigcone spruce or canyon live oak woodland; bigcone-spruce will slowly invade the live oak woodland if fires are kept out for a considerable period. South-facing slopes are covered with chaparral consisting of interior live oak, chaparral whitethorn (Ceanothus leucodermis), bigberry manzanita, and Eastwood manzanita; bigcone-spruce invades this chaparral very slowly.

Fires in the prehuman period undoubtedly prevented the development of extensive bigcone-spruce forests on some sites although remnants of old stands show that this species was much more abundant and widely distributed in early days. Each major fire that burns through this tension zone reduces the extent of the bigcone-spruce. After burning, this forest is replaced by canyon live oak, deerbrush ceanothus, interior live oak, or other chaparral species. During the period of human occupancy, the bigcone-spruce has given way rather markedly and the zone is characterized by many burned-out areas.

RECOVERY OF CHAPARRAL AFTER FIRE

Knowledge of plant succession in the chaparral after forest fire is a valuable watershed-management tool. Plant succession in the chaparral shows a beautiful adaptation to the environmental factor of fire. Along with the evolutionary development of chaparral shrubs, there has also occurred the development of many species of annuals and perennials requiring fire for their reproduction. Seeds of these species lie dormant in the litter or soil during the long periods which may occur between burnings, but when fires occur the seeds are stimulated to immediate germination. The succession of vegetation which develops after fire in the chamise chaparral, for example, is as follows:

1. The first year after burning shows a vigorous development of annual herbs. Certain chaparral plants such as chamise, scrub oak, etc., send up shoots from the burned stumps. Seed of both sprouting and non-sprouting chaparral species (principally Ceanothus) germinate during the first winter, as well as many species of short-lived perennials such as deerweed (Lotus scoparius), bush lupine (Lupinus longifolius), and sticky nama (Nama parryi). These seedlings do not grow more than a few inches in height by the end of the first growing season.

2. The second year shows a great increase in development of the short-lived perennials and the sprouts of the sprouting chaparral. Annuals may be as numerous as during the first year, though certain annual species do not appear at all in the second year. The seedlings of chaparral species are still very small.

3. The third year shows a marked increase in the dominance of short-lived perennials which by now far surpass the sprouting chaparral. The annuals are decreasing, and the chaparral shrub seedlings are still too small to be of much importance.

4. By the fifth year the annuals are usually pretty well gone, and the short-lived perennials have become minor in importance. The bulk of the cover is produced by the sprouting chaparral stumps. The small chaparral seedlings have grown to a height of perhaps 8 or 10 inches, but are still not a vigorous part of the plant cover.

5. Usually by the eighth year the cover is composed entirely of chaparral species. Ceanothus, if present, is rapidly becoming the dominant, and promises soon to surpass the sprouting shrubs such as chamise.

6. By the fiftieth year the short-lived shrubs such as ceanothus are losing their dominance, and at this time the cover opens because the chamise does not produce as heavy a canopy as the ceanothus.

The density of chaparral cover increases very rapidly through the first ten years following fire. Then it increases less rapidly until the maximum density is reached at about forty years after burning. The cover tends to stabilize at this age, but may open up gradually as in the case of the chamise-ceanothus combination. The density attained at forty years depends upon the dominant species, the climate, soil and topography. As a rule, unless there has been exceptional erosion following fire, the chaparral vegetation eventually recovers to about the same density as before burning.

THE HYDROLOGIC CYCLE

P. B. Rowe

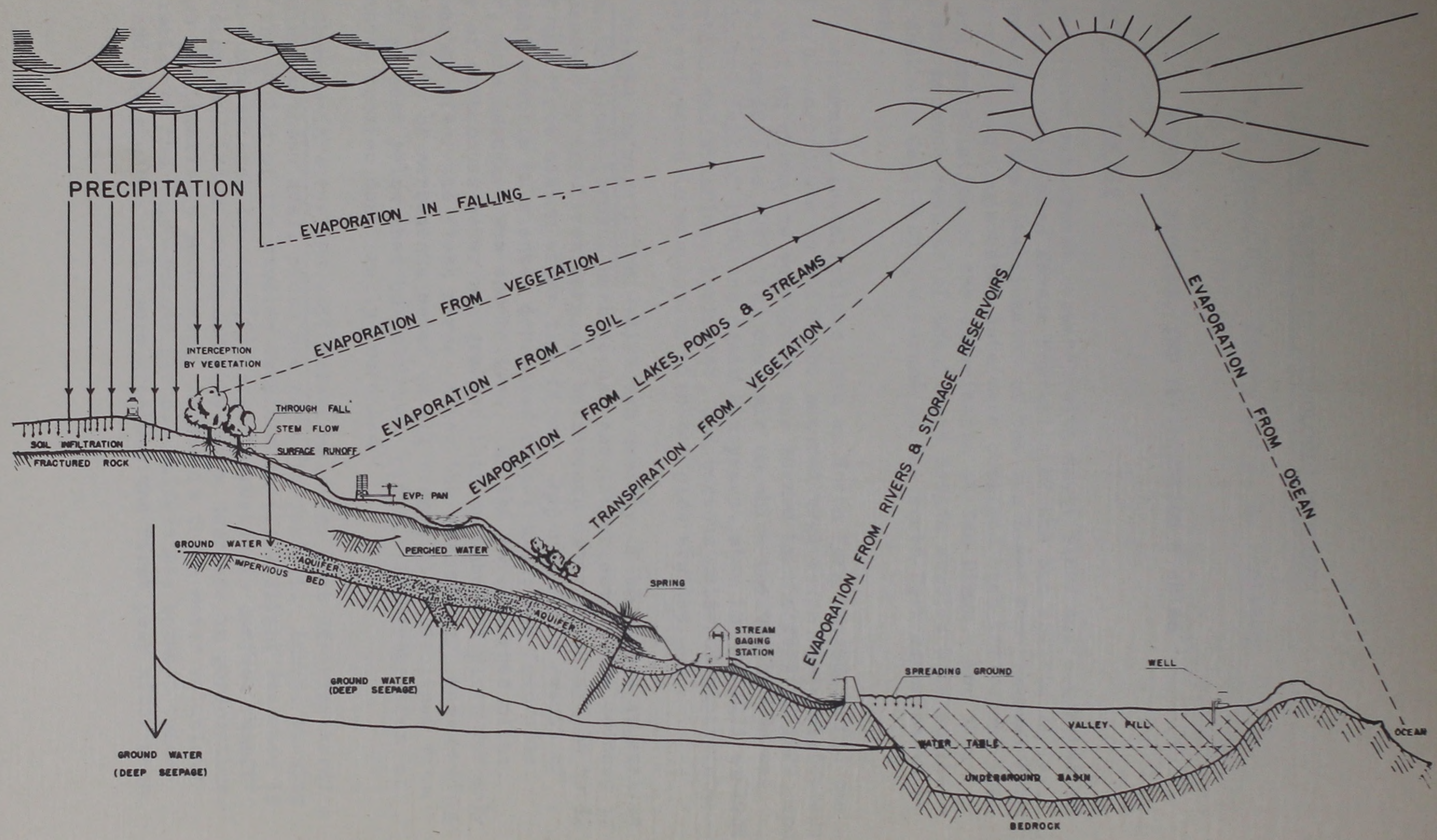
To watershed managers, the hydrologic cycle is a helpful concept, for the full cycle accounts for all of the water in the earth's upper layers from the time it arrives as precipitation until it returns to the air by evaporation. Figure 1 illustrates the cycle.

In watershed management, moisture first assumes hydrologic importance when deposited on the earth's surface in some form of precipitation. A portion of the precipitation is intercepted by the vegetation or other obstructions above the land surface. Part of this intercepted precipitation is returned to the atmosphere by evaporation. Of the precipitation reaching the earth, part falls directly on the surfaces of streams, lakes, and oceans; part reaches streams through surface runoff from the land; and part enters the surface soil and underlying rock structures through infiltration. Part of the water entering the land surface is returned to the atmosphere as direct evaporation, or as transpiration by the vegetation, and part reaches streams, lakes, subterranean water bodies, or the ocean, as underground flow. In the long run, then, the hydrologic cycle is maintained by a balance between precipitation and evaporation from the land and water surfaces.

Watershed management is a recognized practice because water on the earth's surface is subject to some control by man. While man cannot regulate the quantity of precipitation, he can apply important controls to evaporation, transpiration, infiltration, and surface runoff. Control of these phases of the hydrologic cycle can be varied by changing certain conditions in a watershed. This is the function of the watershed manager.

Although we know and recognize all of these phases of the hydrologic cycle, we still lack much knowledge of their magnitude and of the relationships between them. Gaining a better knowledge of these quantities and relationships is a major function of watershed-management research.

THE HYDROLOGIC CYCLE



SOME RESULTS OF HYDROLOGIC RESEARCH

P. B. Rowe, H. C. Storey and E. L. Hamilton

RUNOFF, EROSION, AND INFILTRATION STUDIES

North Fork experiments

Watershed management research with small plots was conducted at North Fork, in the Sierra Nevada foothills of the San Joaquin Valley, before and during the establishment of the San Dimas Experimental Forest. In this work fundamental data were obtained that influenced the design and installation of the experiments at San Dimas. For this reason, and because results of the Sierra Nevada studies have application in southern California, a resumé of the North Fork experiments is given here.

Experimental installations used at North Fork included: (1) one pair of 1/40-acre plots on which the natural vegetation was undisturbed; (2) one pair on which the vegetation was burned in the fall of 1929, and annually from 1931 to 1937; (3) one pair on which the vegetation was burned in the fall of 1930 and again six years later in the fall of 1936. Interception and stemflow, lysimeter, and various meteorological data were also collected in connection with the plot studies.

Changes in vegetation.--Although density of the total vegetative cover on the plots (brush, herbaceous, and litter cover) was reduced 50 to 55 percent by the first burning, herbaceous cover increased 35 to 40 percent the first season after the fire. Apparently a result of additional soluble nutrients, decreased competition, and favorable weather, this increase was short-lived. On the twice-burned plots, density of herbaceous cover was greater than on unburned plots for only four seasons after the first fire. After the second and succeeding burns, density of herbaceous cover on all burned plots declined from 26 to 60 percent below that on unburned plots. The proportion of unpalatable species continually increased.

Changes in water and soil relations.--The most striking results of burning on these small plots are shown in Table 4. Annual burning during the period of the studies resulted in (1) a slight decrease in average evaporational losses, (2) large increases in surface runoff and erosion, and (3) a correspondingly large decrease in percolation. Although quantitatively much less, changes in these water relations were similar on the twice-burned plots. Differences between twice-burned and undisturbed plots were greatest the first year after each burn.

Table 4.- Average yearly disposition of precipitation on plots at North Fork, 1934-38

Plot treatment	Precipitation	Evaporation losses 1/	Surface runoff	Percolation 2/	Erosion
	Inches depth				Lbs/plot
Undisturbed	45.26	19.1	Trace	26.2	0
Burned annually	45.26	17.2	10.3	17.6	1,335

1/ Includes evaporation from the soil, transpiration, and interception loss. (Interception not measured on annually burned plot.)

2/ Percolation through a 48 inch soil depth.

To watershed managers, the significant feature of these changes lies not in the total water yield, but rather in the quantity and distribution of the water. A large proportion of the surface runoff from the burned plots occurred during flood periods. Much of this water was loaded with silt and debris and was therefore unsuited for many uses.

Differences in the water-soil relations of undisturbed and burned plots were caused principally by the effects of burning on infiltration capacity of the soils. By March 1938 average infiltration capacities of the undisturbed, twice-burned, and annually burned plots were approximately 3.5, 0.55, and 0.12 inches per hour, respectively. This reduction in infiltration capacity as a result of burning was caused in most part by (1) the destruction of litter cover and the reduction of organic matter in the surface soil, (2) the reduction in the activities of certain of the soil fauna such as earthworms and burrowing insects, and (3) the plugging of soil pores and the destruction of surface soil structure caused by direct exposure to rainfall, surface runoff, and erosion.

Plot studies at San Dimas

Further studies of runoff and erosion from watershed slopes have been made on two series of nine 1/40-acre plots in the chaparral cover of the San Dimas Experimental Forest (Table 5). The Tanbark Flat series at 2,750 feet elevation is in the ceanothus-oak-chamise subtype and the Fern Canyon series is located in the oak-woodland subtype at 5,000 feet elevation. The vegetative cover on the Tanbark Flat plots has been unburned since 1919. It is representative of probably 20 percent of this subtype on the four southern forests. The Fern Canyon plot vegetation had been unburned for at least 55 years until 1938 when a fire destroyed the cover and consumed most of the litter. Due to the age of the pre-1938 vegetation it was representative of only about 5 percent of this type.

Table 5.- Annual rainfall, runoff, and erosion for 1/40-acre plots, San Dimas Experimental Forest, California

Hydrologic year[1]	Fern Canyon plots: Rainfall	Runoff		Erosion	Tanbark plots: Rainfall	Runoff		Erosion
	In.	In.	Percent of rain	Cu.ft./A	In.	In.	Percent of rain	Cu.ft./A
1935-36	25.0	.3	1.4	1.0	22.0	.2	.7	1.5
1936-37	44.1	.4	1.0	.6	41.0	.1	.2	1.2
1937-38	52.4	.3	.6	1.3	45.1	.5	1.1	1.5
1938-39[2]	22.0	1.4	6.4	272.5	20.2	T.	.1	.7
1939-40	32.3	.6	1.9	33.0	32.3	T.	.1	.5
1940-41	57.8	.6	1.0	10.0	46.6	.1	.1	.5
1941-42	19.5	T.	.2	T.	16.4	T.	.1	.5
1942-43	53.5	.2	.5	T.	45.2	.1	.2	.3
1943-44	40.5	.4	1.0	T.	32.7	T.	.1	T.
1944-45	35.5	.1	.2	T.	29.7	T.	.1	T.
1945-46	30.0	.1	.4	T.	26.1	T.	.2	T.

1/ October 1 through September 30 of succeeding year.

2/ Fern plots burned November 1938.

A marked increase in runoff and erosion was noted from the Fern plots immediately after the vegetation on them was burned in November 1938. This is in contrast to the comparatively uniform performance of the Tanbark plots during the same period. No significant runoff or erosion was measured on either of the two series of plots before the fire. This period included the capital storm of March 1938 when during a three-day period the rainfall on the Tanbark plots was 20.20 inches and on the Fern 22.19 inches. During this storm the maximum hourly rainfall was 1.26 inches, and intensities of approximately 1 inch per hour continued for 4 hours. Yet runoff and erosion from both series of plots were inconsequential. However, after the Fern plots were burned over, a storm of 10.62 inches in December 1938 caused runoff amounting to 6 percent of the rain. With a maximum hourly intensity of 0.68 inches, this storm was sufficient to start an erosive process producing really significant debris movement during the first year after the burn. The reaction resulting from the loss of plant cover on the Fern plots persisted for three years, after which they appear to behave similarly to the Tanbark plots. The yearly runoff of 0.2 and 0.1 percent of the rain on the Tanbark plots means that practically all of the rain went into the soil -- a good illustration of the value of vegetative cover.

Data from plots of this type cannot be applied directly to whole watersheds, but they do supply pointed information concerning the amount of water running off or entering the soil under certain cover conditions.

Infiltrometer studies

Some quantitative influences of vegetation and different types of land use on the infiltration capacities of soils are shown in Table 6. It is of interest that in more than 1,000 infiltration tests in the Pajaro, Santa Maria, and Santa Ynez River drainages, and in the Kennett and San Joaquin areas, no case was found in which heavy grazing or burning of the vegetation, other conditions being equal, failed to result in a decrease in infiltration capacity of the soil. It should be remembered, however, that in some soils with initially high infiltration capacities, large reductions may occur, yet infiltration capacities will still exceed the maximum rainfall intensities of the region. In such soils, reductions in infiltration capacities may have little or no direct effect on surface runoff.

Table 6.- Some effects of land treatment on average infiltration capacities of soils in various cover types of the Santa Maria River drainage, California

Cover types	Degree of use, age of cover, or treatment	Weighted mean infiltration capacities 1/
		Inches/hour
Grassland and sagebrush	Heavy grazing	0.19
	Moderate grazing	0.57
	Light grazing	0.94
Pinyon-juniper	Heavy grazing	0.34
	Moderate grazing	0.51
	Light grazing	0.84
Semi-barren	Heavy and moderate grazing	0.12
	Light to no grazing	0.55
Chamise	0-3 years after burning	0.21
	4-15 years after burning	0.36
	Over 16 years after burning	0.40
Chaparral and chaparral-woodland	0-3 years after burning	0.36
	4-7 years after burning	0.95
	7-15 years after burning	1.46
	Over 16 years after burning	1.96
Cultivated	Cleantill	0.09
	Treated (cover crop)	0.34

1/ Infiltration capacities determined by use of the North Fork infiltrometer, and adjusted to experienced watershed conditions by analyses of precipitation and streamflow for several storms.

Rainfall interception studies

A study of the interception of rainfall by chaparral vegetation was made at Tanbark Flat on the San Dimas Experimental Forest during the years 1942-45 on a plot with an area of 970 square feet (10 ft. x 97 ft.). The vegetation on this plot had a density of about 70 percent and was composed chiefly of California scrub oak and hairy ceanothus. The amount of throughfall, rain falling on the ground or reaching it as drip from the vegetation, was measured in a trough 80 feet long and 9 inches wide set at ground level under the canopy. The 149 stems on the area were collared with sheet-lead troughs which diverted into measuring tanks all of the rain that collected on the shrub canopy and ran down the stems.

Measurements of throughfall and stemflow for 50 storms indicate the following disposition of the total rainfall of 83.25 inches:

67.03 inches or 81 percent of the rain reached the ground as throughfall.

6.96 inches or 8 percent of the rain reached the ground as stemflow.

9.26 inches or 11 percent of the rain was intercepted by the canopy and evaporated. Thus 11 percent of the precipitation made no contribution to ground water or surface runoff.

The above figures are simple totals for all storms measured. If the storms are segregated into size classes we find that the interception loss becomes proportionally less as the storm magnitude increases, as shown in Table 7.

Table 7.- Summary results of interception study on the San Dimas Experimental Forest, California

Storm size class, inches	No. of storms	Rainfall	Throughfall		Stemflow		Interception loss	
		In.	In.	Percent of rain	In.	Percent of rain	In.	Percent of rain
.10 - .25	10	1.70	.79	46	.06	4	.85	50
.26 - .50	6	2.33	1.47	63	.14	6	.72	31
.51 - 1.00	14	10.28	7.69	75	.76	7	1.83	18
1.01 - 2.00	10	13.26	10.76	81	.97	7	1.53	12
2.01 - 6.00	5	16.05	13.09	82	1.34	8	1.62	10
6.01 - 12.00	5	39.63	33.23	84	3.69	9	2.71	7
Total	50	83.25	67.03	81	6.96	8	9.26	11

Seven seasons of interception-stemflow measurements in chaparral types of the Sierra Nevada foothills near North Fork showed an interception loss averaging only about 5 percent of the total precipitation. Nearly 20 percent of the total precipitation was caught by the vegetation, but of this amount 75 percent, equivalent to 15 percent of the total precipitation, reached the soil as flow down the stems of the brush. The density of the vegetation averaged from 40 to 50 percent. In a 70-year-old second growth ponderosa pine stand at Bass Lake, near North Fork, with a canopy cover of 40 to 50 percent density, the interception loss averaged 12 percent of annual precipitation.

WATERSHED STUDIES

To make the results of water-cycle studies directly applicable to whole watersheds, it is desirable that the experimental work be done on whole watersheds. Facilities for work on this scale -- including extensive watersheds protected from fire and other disturbance, weirs for measuring runoff, reservoirs for measuring eroded debris, and the instruments required for measuring climatic and atmospheric factors -- are available on the San Dimas Experimental Forest.

Disposition of precipitation

Of the many studies under way on the San Dimas Experimental Forest, the one of perhaps the most direct interest to watershed managers concerns the disposition of precipitation after it reaches the ground. How much of the precipitation is accounted for by streamflow? How much is lost through interception? How much returns to the atmosphere through evaporation and transpiration? How much is retained in underground reservoirs?

Measurements of precipitation and streamflow for four seasons in several watersheds of the San Dimas Experimental Forest are given in Table 8. The values in this table bring out the great variation in precipitation-streamflow relations from year to year.

A more complete picture of the disposition of precipitation in a single rain year is shown in Table 9, which gives an accounting for 12 watersheds in southern California, and also the average behavior of 19 watersheds, as calculated from the results of forest influences studies. It will be noted that the disposition of precipitation, as well as the amount, varies considerably among the several watersheds, even in the same year. This is particularly true of streamflow and retention (see footnote 1, Table 9).

Table 8.- Some precipitation-streamflow relations for four watersheds on the San Dimas Experimental Forest, California

Season and watershed	Area	Precipitation	Streamflow	Streamflow as percent of precipitation
	Sq.mi.	Inches	Inches	
Season 1934-35				
Wolfskill	2.39	31.3	2.0	6.3
North Fork, San Dimas	4.23	32.5	2.2	6.7
Volfe	1.16	34.5	2.4	6.9
Monroe	1.37	33.5	2.6	7.7
Season 1935-36				
Wolfskill	2.39	23.1	1.5	6.4
North Fork, San Dimas	4.23	22.8	1.3	5.7
Volfe	1.16	25.5	2.1	8.2
Monroe	1.37	25.5	1.5	5.8
Season 1937-38				
Wolfskill	2.39	43.8	14.4	32.8
North Fork, San Dimas	4.23	43.8	16.4	37.4
Volfe	1.16	41.9	16.5	39.4
Monroe	1.37	41.4	14.5	35.0
Season 1940-41				
Wolfskill	2.39	48.9	9.5	19.4
North Fork, San Dimas	4.23	48.8	12.5	25.6
Volfe	1.16	50.9	12.3	24.2
Monroe	1.37	50.4	11.1	22.0

Table 9.- Disposition of precipitation in some representative watersheds of southern California, October 1, 1940, to September 30, 1941

Watershed unit	1 Precipitation	2 Stream flow	3 Interception loss	4 Evaporation, transpiration	5 Retention 1/ 1-(2+3+4)	6 Maximum retention 2/
			- - - Inches depth - - -			
Piru Creek	45.2	9.8	2.5	17.0	15.8	23.4
Pacoima Creek	48.9	17.4	3.1	14.8	13.6	22.3
Haines Canyon	57.1	9.3	3.1	16.7	28.0	36.5
Big Santa Anita Creek	65.2	25.1	3.5	13.8	22.8	33.7
Fish Canyon	60.2	26.9	3.4	14.9	15.0	28.9
East Fork San Gabriel	59.7	27.7	3.1	16.0	13.0	29.9
Dalton Creek	48.8	11.5	3.4	14.0	19.9	27.1
San Dimas Creek	48.0	11.1	3.4	13.7	19.8	27.5
San Antonio Creek	78.6	38.3	3.1	16.7	20.5	47.3
City Creek	62.5	17.5	4.4	15.7	24.9	32.8
Big Rock Creek	60.0	29.2	2.6	15.7	12.5	33.6
West Fork Mojave River	37.1	14.5	2.5	17.2	2.9	13.9
Average of 19 watersheds 3/	56.1	20.0	3.2	14.5	18.4	28.9

1/ Includes underground flow that feeds the natural underground basins of the valleys by drainage through the soil and subsurface rock, without appearing as surface streamflow.

2/ Retention toward end of rainy season, before streamflow and evapotranspiration losses of late spring, summer, and fall.

3/ Average of 19 typical watersheds of the Angeles National Forest, extending from Pacoima Creek to San Antonio Creek along south slope of the San Gabriel Mountains, including 8 of the watersheds listed above.

Water retention capacity

The determination of water retention capacities for whole watersheds is another problem of importance to watershed managers. "Water retention capacity" is the capacity of the soil and substrata to hold water in temporary storage. The water so held is released slowly by subterranean flow to springs and streams, and by deep seepage to the valley fill or the ocean. It is obvious that the degree to which increases in infiltration can reduce surface runoff and streamflow is dependent upon the capacity of the soil and the underlying rock formations to absorb, hold, and transmit water.

Water retention capacities of 36 representative watersheds of the southern California national forests have been determined in connection with the fire-damage-appraisal study. Precipitation and runoff records of the 1940-41 rain season were used in this analysis because that year brought an unusually large amount of rainfall in well-distributed storms, and at rates sufficiently low to favor maximum water intake and retention.

This study showed that the maximum depth of water was retained toward the end of the rain season, during late winter and early spring, and averaged nearly 30 inches in depth (see last column of Table 9). The maximum depth in individual watersheds ranged from below 20 inches to over 40 inches.

In only one watershed did the amount of streamflow during a storm period of this 1940-41 rain season exceed 30 percent of the storm precipitation. In fact, during the many years for which streamflow records are available for these streams, there were only three cases in which the stream runoff of a storm period was as much as 50 percent of the precipitation. These three cases of unusually high runoff occurred during the great storm of March 1938, which was marked by exceptionally <u>high intensities</u> as well as <u>large amounts</u> of rainfall. Analysis of these cases showed that the high storm runoff resulted from the fact that rainfall rates, at times during the four-day storm, exceeded the capacities of the watersheds to take in water.

These results indicate that, for the period of record included in the analysis, no watershed reached or closely approached complete saturation. This means: (1) that the temporary water-storage capacities of most of the mountain watersheds of southern California are in most years well in excess of the highest expected amounts of storm precipitation, and (2) that if, through watershed management, a larger portion of storm precipitation is delivered to temporary subsurface storage, flood peaks and erosion rates can be reduced and interstorm streamflow increased.

EFFECTS OF FOREST FIRE ON FLOOD PEAKS AND EROSION RATES

Because of its function in promoting infiltration and reducing surface runoff and erosion, maintenance of the plant cover is of primary importance in the chaparral watersheds of southern California. Removal of the vegetation by fire normally results in increased peak flows of stream runoff and rates of soil erosion.

Records of streamflow from burned and long-unburned (unburned for 40 or more years) watersheds in southern California show that the first year after burning, peak flows are increased from 2 to 30 times, depending upon the size of storm. Peak flows from burned areas do not return to normal until 20 to 60 years after a fire. These general relationships are shown in the following tabulation:

Size of storm	Increase in peak flow following fire	Period of return to normal flow
	Times	Years
Small	10-30	20
Medium	3-10	40
Large	2-3	60

Annual erosion rates are increased, on the average, about 35 times the first year after a complete burning of a good chaparral cover, and 8 to 10 years are required for erosion rates to return to normal. Erosion rates during this recovery period average 9 to 10 times those before burning. If deep gullying, such as occurs in some areas, is started after burning, the long-time average erosion rates and the time required for recovery may be greatly increased. Data were not available to permit determination of the effects of burning on deep gullying and the resulting erosion rates.

It should be remembered that the foregoing figures of average increases in runoff peak and erosion rates as a result of burning are for watersheds with initially good cover. In watersheds with appreciable amounts of barren areas, or areas of very sparse vegetation, these effects of burning may not be so pronounced.

Normal and after-burn flood peaks and erosion rates for some representative watersheds of the southern California national forests are given in Table 10.

Table 10.- Estimated one hundred-year flood peaks and annual erosion rates for some representative watersheds of the southern California national forests 1/

Watershed units	100-year flood peaks 2/						Annual erosion rates			
	Unburned 3/	Years after 100% burn					Unburned 4/	Years after 100% burn		
		1st	3d	7th	10th	30th		1st	3d	5th
	- - - Cu. ft./sec./sq.mi. - - -						- - - Cu. yds./sq.mi. - - -			
LOS PADRES NATIONAL FOREST										
Sisquoc River	120	230	180	150	140	130	720	24,000	5,500	2,700
Juncal Creek, above dam	290	580	430	370	340	310	2,100	72,100	16,300	8,000
Matilija Creek	280	570	430	370	330	310	2,600	90,700	20,500	10,100
ANGELES NATIONAL FOREST										
Tujunga, above dam	300	540	420	370	340	320	1,800	51,800	11,900	6,000
Santa Anita, above dam	390	780	580	500	460	420	3,800	133,000	30,000	14,800
San Gabriel, W. Fork above dam	500	910	710	620	570	540	6,100	176,300	40,300	20,700
SAN BERNARDINO NATIONAL FOREST										
Mill Creek, above dam	250	410	330	290	270	260	1,400	30,400	7,200	3,800
Lytle Creek	280	400	340	310	300	290	2,500	35,800	9,100	5,400
Cucamonga Creek	330	630	470	410	380	350	4,700	131,600	30,200	15,300
CLEVELAND NATIONAL FOREST										
San Juan Creek	200	370	290	250	230	220	640	19,100	4,400	2,200
Sweetwater Creek, above dam	190	300	250	220	210	200	1,400	26,000	6,400	3,500
Cottonwood Creek, above dam	200	300	250	230	220	210	5,600	27,700	10,200	7,600

1/ Estimates based on analysis of available precipitation, streamflow, erosion, and other pertinent data.

2/ Flood peak expected to be equaled or exceeded on an average of once in 100 years.

3/ Vegetation unburned for 40 or more years.

4/ Vegetation unburned for 10 or more years.